JOURNAL

OF THE

New York Entomological Society

Vol. L March, 1942 No. 1

THE BEHAVIOR OF CERTAIN INSECTS TO VARIOUS WAVE-LENGTHS OF LIGHT

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This paper is the third of a series outlining the behavior of certain insects to light of various wave-lengths. The first two were published in the Journal of the New York Entomological Society, Vol. XLIX, p. 1–20; p. 149–159, 1941, and set forth the behavior under certain conditions, briefly an exposure for 15 minutes to eight wave-length bands of light of equal physical intensities from 3650 Å to 7400 Å. These lights were arranged in a circle around a central introduction point. The distance from the introduction point to the Corning monochromatic filter combinations was approximately one foot. Under the conditions, as described fully in the two previous papers, a more or less uniform type of behavior took place, in that for eighteen of the twenty-nine photopositive species tested, a wave-length band of 4700–5280 Ångstrom units attracted more individuals than any other band.

The present paper includes (1), a report of the results of additional tests in the circular apparatus described in the two previous papers, (2), an account of the behavior of various species in a new sector type of testing box, and (3), the results obtained in an additional piece of testing equipment which permitted more latitude in the variation of the physical intensities of the wave-lengths. The dates on which the various species were tested, relative humidity and temperature are found in Tables 3 and 4.

(1) BEHAVIOR OF ADDITIONAL LOTS OF INSECTS IN THE CIRCULAR TESTING APPARATUS

Before referring to Table 1, which is a detailed record of the behavior of additional lots of insects, it may be well to repeat that the insects in question were exposed for fifteen minutes to light of various wave-lengths, or colors, determined by the passage of light from forty-watt frosted Westinghouse Mazda lamps and a General Electric Mazda mercury lamp [Type A–H 4, 100 watts, which supplied the ultra-violet], through appropriate Corning monochromatic filter glass combinations. The physical intensities of the wave-lengths were equalized by regulating the distances between the source lamps and the filter combinations. The lamps were operated at 110 volts, alternating current. The method of handling the insects was identical to that described in the first paper. They were introduced approximately one foot from the filters. For convenience in making comparisons in relative intensities, the introductory intensity in this case will be designated as 100. In succeeding tests we were able, in our other equipment, to introduce the insects at distances of 1, 2, 3, 4, 5 and 6 feet from the filters. By adopting 100 as the introductory intensity when the insects were introduced at a distance of one foot from the filters, the relative introductory intensities at the other distances were approximately 25, 11, 6, 4 and 3.

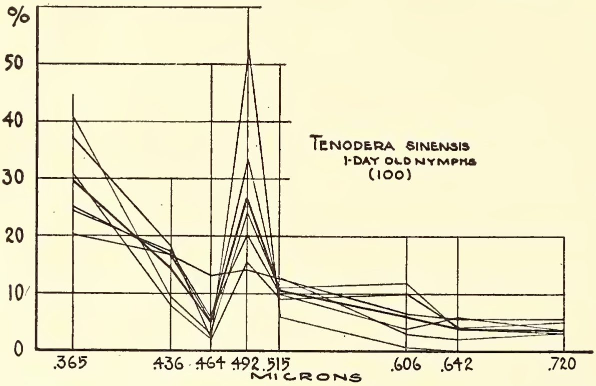

FIG. 1. Behavior of six different lots of 1-day-old nymphs of *Tenodera sinensis.* Heavy line indicates behavior of six lots combined.

In Table 1 the behavior of five species is set forth and it may be noted that in general their reactions to the eight light bands, to which they were exposed, were like the reactions previously recorded for other species. In other words, the light band extending from 4700–5280 Å (blue-blue-green) attracted the largest percentage of insects in each case except for *Macrocentrus ancylivorus* and for one-day-old nymphs of *Tenodera sinensis* in two cases, which were stimulated more or less equally at 3650–3663 Ångstrom units (ultra-violet) and by the 4700–5280 Å band. In the case of *Tenodera sinensis* (one-day-old nymphs) the largest percentage of these alternated between 3650–3663 and 4700–5280 Å. When the results of six tests, with new individuals each time, were totalled, 3650–3663 and 4700–5280 seem to be about equal in stimulating efficiency. This is shown in Figure 1 by the behavior curves of six different batches of one-day-old nymphs and by the heavy black line representing the combined responses for the six tests.

(2) BEHAVIOR OF VARIOUS SPECIES IN THE SECTOR TYPE EQUIPMENT

Because of certain inherent limitations of the circular apparatus, and the impossibility of having a completely dark chamber (for photonegative species), a new and larger equipment was built. This equipment (Figs. 3 and 4) was built essentially on a circular sector design. The filters and filter chambers were along the circular arc, the introduction chamber at the centre, and the radial sides included an angle of 72 degrees. Immediately behind the introduction chamber was a small rectangular dark chamber which permitted insects repelled by the light to find totally dark spaces. Thus after the insects were placed in the introduction chamber they could move either to the light or away from it to the black chamber. Ten wave-length bands were used, in their natural order, along the convex side of the equipment and when the insects emerged from the center of the introduction chamber, towards the light, they were exposed to all wave-lengths for a distance of at least 18 inches and within this area they had the opportunity of making a choice.

As in the circular apparatus forty-watt, frosted, Westinghouse Mazda lamps were used and the ultra-violet was supplied by a

TABLE 1

Name	No. tests	Total No. insects involved	Per cent of total in center	Per cent reacting	Distribution of those reacting to various wave-lengths*								Relative physical intensity at point of introduction
					3650 Å	4360 Å	4640 Å	4920 Å	5150 Å	6060 Å	6420 Å	7200 Å	
					Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Orthoptera													
Mantidæ													
Tenodera sinensis Sauss (1 day old nymphs)	1	224	40	60	31.0	8.1	2.2	52.0	6.0	0.7	0.0	0.0	100
Tenodera sinensis Sauss (1 day old nymphs)	1	301	27	73	41.1	9.6	3.2	24.2	13.2	3.2	2.3	3.2	100
Tenodera sinensis Sauss (1 day old nymphs)	1	257	14	86	24.4	17.6	6.0	20.0	11.3	11.7	4.0	5.0	100
Tenodera sinensis Sauss (1 day old nymphs)	1	352	32	68	20.5	16.8	5.6	33.4	10.0	4.1	5.9	3.7	100
Total of above plus two reported previously	...	....	......	......	29.5	14.6	5.0	26.5	10.6	6.1	4.0	3.7	100
Coleoptera													
Chrysomelidæ													
Leptinotarsa decemlineata Say	1	307	27	73	13.0	10.0	4.0	49.0	13.0	6.0	2.0	3.0	100
Coccinellidæ													
Megilla fuscilabris Muls.	3	326	32	68	12.7	11.7	9.0	30.0	15.0	8.0	7.3	6.3	100
Curculionidæ													
Myllocerus castaneus Roelofs	3	176	32	68	14.0	20.5	4.1	23.0	22.1	10.6	5.7	0.0	100
Hymenoptera													
Macrocentrus ancylivorus	1	101	30	70	40.0	9.0	1.0	38.0	10.0	1.0	1.0	0.0	100

* The Angstrom units represent the peak intensities of the bands.

General Electric Mazda mercury lamp (Type A–H 4, 100 watts). Corning filter glasses were used to isolate specific spectral bands. Each filter, or combination of filters, was, when in place, equally distant from the chamber into which the insects were introduced. The distance settings from the 40-watt lamps to the filter combinations, in order to equalize the physical intensities of the wave-lengths, were in all experiments the same as those shown in column 3, Table 2, JOURNAL NEW YORK ENTOMOLOGICAL SOCIETY, Vol. XLIX, p. 10. The ten wave-length bands to which the insects were exposed were those shown in column 3, Table 1, JOURNAL NEW YORK ENTOMOLOGICAL SOCIETY, Vol. XLIX, p. 9. It should be kept in mind that as the introduction chamber in this sector type of equipment was six feet away from the filter combinations, the physical intensities of the wave-lengths reaching the introduction chamber were only 1/36th of what they were when the testing was done in the circular apparatus where the insects were introduced one foot away from the filter combinations.

Thus, although the triangular apparatus enabled us to use ten wave-length bands in the spectrum and was equipped with a dark chamber, it forced us to introduce our specimens to energy that was only 1/36th as intense as that used formerly in the circular apparatus. This led to the construction of other equipment that shed more information upon insect behavior to light.

DESCRIPTION OF TESTING EQUIPMENT

The testing box, exclusive of the dark chamber and the light stand, was built of plyboard in the form of a sector having a radius from the center of the introduction chamber to the inside surface of the glass filters of 72 inches, and an outside chord of 86 inches. The arc of the sector was divided into 12 equal parts and, allowing for supports and insulating molding, we thus obtained 12 compartments six inches wide by three inches deep. The outer surface of each such compartment consisted of a plyboard slide with a 1¾-inch square opening in the lower left-hand corner over which the glass filters were placed and held firmly with thumb screws. Each of these compartments was divided in half with a plyboard strip, so that one-half of each compartment was in total darkness during operation, while the other half was lighted. A plyboard slide formed the top of each compartment and two holes were bored in each top, then plugged with cotton. In using very active insects chloroform was dropped on these plugs and the insects killed at the end of a test. A slight space was allowed between the hinged tops of the central chamber and the tops of the outer compartments for the insertion of a metal slide at the completion of each trial. In this manner the insects were trapped in the outer compartments.

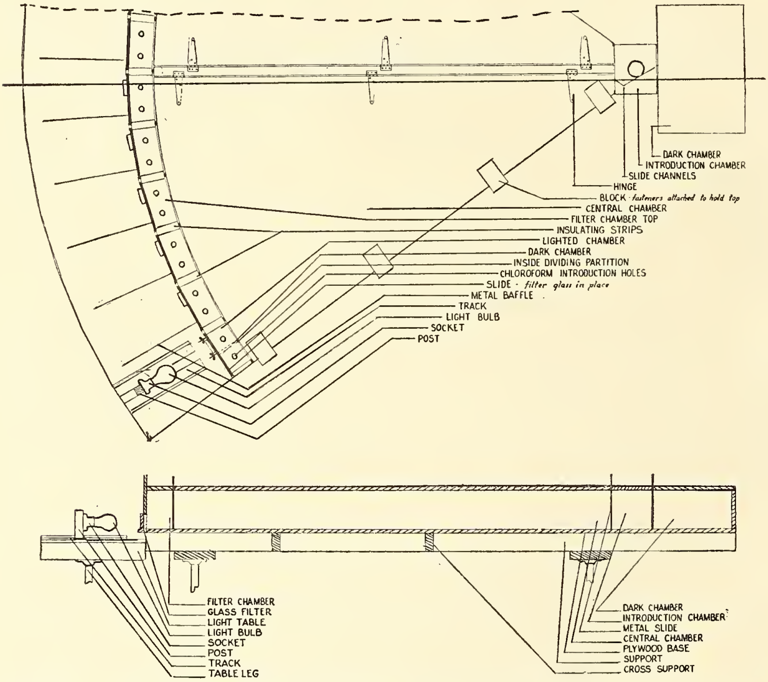

FIG. 2. (top) Top view of testing equipment showing principal parts and some details. (bottom) Vertical section through the centre of testing equipment.

A stand was constructed to hold the light bulbs. This stand was made of thin plyboard, well braced and mounted on casters so that it could be wheeled away from the end of the testing box to give easier access to the filter chambers. Tracks made of thin wooden strips were centered behind each filter so that when the stand was in place the bulbs, mounted on wooden posts in the tracks, could be moved to the proper distances behind the filters. Metal baffles, painted black, were also fastened to the light stand to cut out interference from adjoining bulbs.

The two lids of the large central chamber were hinged along a central strip running the length of the chamber, so that at the end of a test these lids could be opened upward and braced, while the insects within were counted.

The introduction chamber, having an inside measurement of $6\frac{1}{4}$ inches by 6 inches, had a separate lid with a $2\frac{1}{2}$ inch hole bored centrally. It was the usual procedure to drop the insects from their containers into a funnel placed in this opening and thus to the floor of the introduction chamber. Channels were provided in front of the introduction chamber and behind it. These were covered during a test to prevent light leakage, but at the completion of a test metal slides were inserted thus trapping any remain-

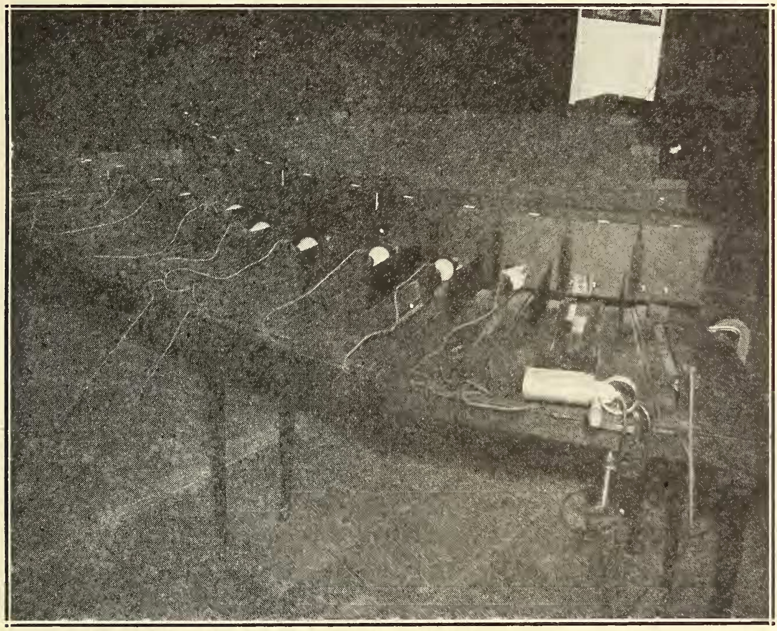

FIG. 3. View of testing equipment with lids closed.

ing insects, so that they might be counted. The dark or black chamber, which had an inside measurement of 18 inches by $12\frac{1}{4}$ inches, was added behind the introduction chamber and, of course, the insertion of the metal slide dividing the introduction chamber and the dark chamber served to trap in the dark chamber any insects that remained there at the completion of a test. The top of the dark chamber was removable so that the insect count could be obtained.

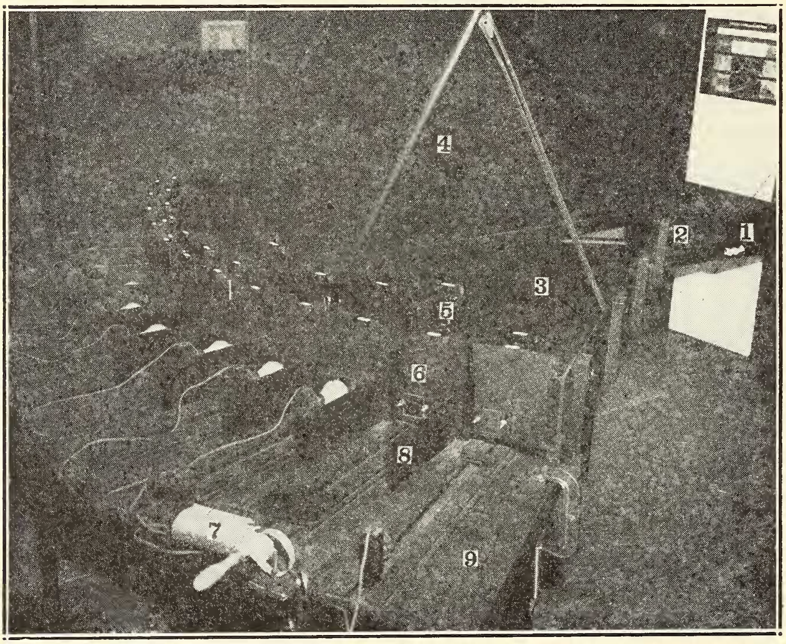

FIG. 4. View of testing equipment with one lid open. 1, dark chamber; 2, introduction chamber; 3, central chamber; 4, lid over one-half of top; 5, metal slide pulled up, this slide together with wooden slide 6 holding filters constitute two sides of filter chamber; Slide 5 also separates filter chamber from central chamber 3; 6, wooden slide holding filters, when removed exposes lighted and dark compartments of filter chamber so insects may be counted. At end of experiment metal slides like 5 are replaced, trapping the insects in the different filter chambers; 7, mercury lamp or source of ultra-violet; 8, metal baffle; 9, removable stand holding tracks and lamps.

Molding was used on all joints in the box and all possible care was taken to insure light tightness of the whole apparatus. The testing box was well braced with two by fours to prevent warping. The apparatus and all its parts were painted with a dull black paint (Figs. 3 and 4).

The insects were placed in the introduction chamber, after the lamps were on and all filter chambers were open. At the ends of the exposure periods the filter chambers were closed by metal slides and the central compartment, introduction chamber and dark chamber also were separated from each other in the same way. Counts were then made. So few insects went to the dark compartments alongside the lighted ones, that it was not thought necessary to report them separately. In the tables they are included with those listed as occurring in the dark chamber. The time of exposure was varied in accordance with the activity of the species and represents, in our judgment, the time needed for a reaction of one kind or another to take place.

RESULTS

In Table 2 there are presented the results of exposing twenty species of insects, mostly Coleopterous ones, to ten wave-length bands in the sector type equipment. By consulting the percentage distributions of the individuals reacting to the various wave-length bands, and by an examination of the behavior curves (Plates I and II), it may be noted at once that, with a few exceptions, the largest numbers of most of the species reacted positively to 3650–3663 Ångstrom units (ultra-violet). This took place when the intensity at the introduction point was 3, or 1/36th of the intensity at the introduction point in the circular apparatus.

Such species as *Leptinotarsa decemlineata, Chrysochus auratus, Scolytus multistriatus, Hylurgopinus rufipes* and *Tetraopes tetraophthalmus,* which were tested in both types of apparatus and which for the most part showed a peak response to 4700–5280 Ångstrom units (blue-blue-green) when they were introduced at a relative intensity of 100 (1 foot away from filters), gave a peak response to 3650 Ångstrom units (ultra-violet) when introduced at a relative intensity of 3 (6 feet away from filters).

Macrocentrus ancylivorus, when exposed to an introductory intensity of 100 exhibited peaks of equal magnitude at 3650–

TABLE 2

Name	No. tests	Total No. insects involved	Exposure minutes	Per cent in black chamber†	Per cent in introd. chamber	Per cent in center	Per cent reacting to wave lengths	Relative physical intensity at point of introduction
Coleoptera								
Lampyridæ								
Celetes basalis Lec.	3	262	25	8	22	42	28	3
Coccinellidæ								
Coccinella novemnotata Hbst.	2	145	20	11	17	25	47	3
Chrysomelidæ								
Disonycha quinquevittata Say	2	135	15	19	20	15	46	3
Blepharida rhois Forst.	3	407	30	4	19	23	54	3
Blepharida rhois Forst.	3	270	20	2	3	41	54	5
Chrysochus auratus (Fab.)	3	240	45	5	15	44	36	3
Lina lapponica Linn.	1	232	30	5	32	40	23	3
Lina lapponica Linn.	1	54	30	4	2	22	72	5
Galerucella xanthomelæna Schr.	1	219	20	2	53	11	34	3
Plagiodera versicolora Laich	2	101	25	6	5	40	49	3
Crioceris asparagi Linn.	3	502	40	2	18	58	22	3
Crioceris asparagi Linn.	1	76	30	0	3	23	74	3
Cerambycidæ								
Tetraopes tetraophthalmus Foer.	3	272	35	8	13	48	31	3
Tetraopes tetraophthalmus Foer.	3	405	40	2	0	73	25	5
Scolytidæ								
Hylurgopinus rufipes (Eich.)	1	272	30	3	47	25	25	3
Scolytus multistriatus Marsham	2	848	15	4	36	38	22	3
Scolytus multistriatus Marsham	1	287	30	7	25	29	39	3
Scarabæidæ								
Serica iricolor Say	3	382	20	17	9	36	38	3
Macrodactylus subspinosus Fab.	4	283	20	0	0	34	66	5
Macrodactylus subspinosus Fab.	3	254	15	2	14	15	69	3
Autoserica castanea Arrow (9:10 P.M.)	3	296	20	26	31	21	22	3

TABLE 2 (*Continued*)

Name	Distribution of those reacting to various wave-lengths‡									
	3650 Å	4360 Å	4640 Å	4920 Å	5150 Å	5460 Å	5750 Å	6060 Å	6420 Å	7200 Å
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Coleoptera										
Lampyridæ										
Celetes basalis Lec.	43	1	1	6	18	11	4	6	7	3
Coccinellidæ										
Coccinella novemnotata Hbst.	35	10	4	12	20	7	6	0	4	2
Chrysomelidæ										
Disonycha quinquevittata Say	11	16	18	32	13	6	0	0	2	2
Blepharida rhois Forst.	20	16	10	29	15	5	3	1	1	0
Blepharida rhois Forst.	16	26	16	20	6	8	3	1	3	1
Chrysochus auratus (Fab.)	47	11	10	6	8	6	3	3	5	1
Lina lapponica Linn.	62	7	2	21	6	0	0	0	2	0
Lina lapponica Linn.	64	2	8	8	8	5	0	5	0	0
Galerucella xanthomelæna Schr.	35	22	11	11	7	4	1	2	7	0
Plagiodera versicolora Laich	72	0	6	8	6	2	2	2	0	2
Crioceris asparagi Linn.	50	9	6	18	6	1	3	0	4	3
Crioceris asparagi Linn.	50	14	3	22	6	0	0	0	3	2
Cerambycidae										
Tetraopes tetraophthalmus Foer.	29	13	6	18	12	8	6	6	1	1
Tetraopes tetraophthalmus Foer.	51	9	4	9	10	2	4	5	5	2
Scolytidæ										
Hylurgopinus rufipes (Eich.)	52	3	3	5	9	5	10	3	10	0
Scolytus multistriatus Marsham	27	6	1	17	24	6	3	9	7	0
Scolytus multistriatus Marsham	34	4	4	14	18	13	0	7	6	0
Scarabæidæ										
Serica iricolor Say	50	10	2	7	12	7	4	3	3	2
Macrodactylus subspinosus Fab.	24	7	3	21	23	10	2	6	2	2
Macrodactylus subspinosus Fab.	39	7	6	27	9	6	1	3	2	0
Autoserica castanea Arrow (9:10 P.M.)	73	3	0	9	2	3	0	3	1	6

TABLE 2 (*Continued*)

Name	No. tests	Total No. insects involved	Exposure minutes	Per cent in black chamber†	Per cent in introd. chamber	Per cent in center	Per cent reacting to wave lengths	Relative physical intensity at point of introduction
Chrysomelidæ								
Leptinotarsa decemlineata Say	3	196	45	7	11	50	32	3
Leptinotarsa decemlineata Say	3	533	20	0	0	48	52	5
Leptinotarsa decemlineata Say	1	202	120	4	6	23	67	3
Leptinotarsa decemlineata Say*	3	817	60	8	16	46	30	3
Galerucella notata (Fab.)	3	546	30	5	19	19	57	3
Scarabæidæ								
Popillia japonica Newm.	3	287	25	3	6	40	51	3
Popillia japonica Newm.	3	302	30	2	0	53	45	5
Popillia japonica Newm.	3	358	45	2	14	32	52	3
Popillia japonica Newm.	3	437	20	6	5	27	62	3
Popillia japonica Newm. ♀	3	201	15	5	8	54	33	3
Popillia japonica Newm. ♂	3	192	15	2	6	43	49	3
Popillia japonica Newm.	1	276	20	3	5	25	67	3
Popillia japonica Newm.§	2	697	20	3	3	21	73	3
Hymenoptera								
Braconidæ								
Macrocentrus ancylivorus Roh.	1	47	30	6	11	15	68	3
Apidæ								
Apis mellifica L.	3	278	15	7	32	17	44	3
Apis mellifica L.	1	108	15	11	13	22	54	3
Hemiptera								
Coreidæ								
Leptocoris trivittatus Say	1	359	15	27	17	25	31	3

* Positions of 3650 Å and 4920 Å reversed.

† These percentages include the relatively small numbers that went to the black chambers between the light chambers.

‡ Ångstrom units represent peak intensities of bands.

§ Filters in disarray.

TABLE 2 (*Continued*)

Name	Distribution of those reacting to various wave-lengths‡									
	3650 Å	4360 Å	4640 Å	4920 Å	5150 Å	5460 Å	5750 Å	6060 Å	6420 Å	7200 Å
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Chrysomelidæ										
Leptinotarsa decemlineata Say	61	13	5	11	0	7	3	0	0	0
Leptinotarsa decemlineata Say	23	12	8	22	12	10	8	2	2	1
Leptinotarsa decemlineata Say	25	20	4	19	4	9	7	3	5	4
Leptinotarsa decemlineata Say*	31	8	9	27	12	3	5	2	3	0
Galerucella notata (Fab.)	14	10	6	33	20	7	6	3	1	0
Scarabæidæ										
Popillia japonica Newm.	22	14	10	26	22	3	2	1	0	0
Popillia japonica Newm.	6	2	8	35	30	13	2	2	2	0
Popillia japonica Newm.	10	11	7	26	26	14	2	2	1	1
Popillia japonica Newm.	27	9	8	18	20	7	4	4	3	0
Popillia japonica Newm. ♀	18	17	13	32	24	6	0	5	3	2
Popillia japonica Newm. ♂	15	19	11	23	19	8	1	2	1	1
Popillia japonica Newm.	14	15	14	25	18	7	2	2	2	1
Popillia japonica Newm.§	10	12	5	13	23	16	8	8	3	2
Hymenoptera										
Braconidæ										
Macrocentrus ancylivorus Roh.	44	6	6	29	6	6	0	0	3	0
Apidæ										
Apis mellifica L.	31	5	8	16	16	6	5	6	6	1
Apis mellifica L.	38	14	2	17	5	9	5	2	3	5
Hemiptera										
Coreidæ										
Leptocoris trivittatus Say	22	17	7	23	16	5	3	2	4	1

* Positions of 3650 Å and 4920 Å reversed.

† These percentages include the relatively small numbers that went to the black chambers between the light chambers.

‡ Ångstrom units represent peak intensities of bands.

§ Filters in disarray.

3663 Å and in 4700–5280 Å. When the relative introductory intensity was 3, the peak at 4700–5280 Å became secondary in comparison with 3650–3663 Å. The potato beetle, *Leptinotarsa decemlineata,* which was tested quite extensively, in new lots each time, exhibited the same type of behavior to a pronounced degree.

The Japanese beetle, *Popillia japonica,* which exhibited comparatively little interest in 3650–3663 Å, and which gave a peak response to 4700–5280 Å, when the introductory intensity was 100, did not follow the behavior of the other species so strongly when the introductory intensity was reduced to 3, but the responses to 3650–3663 Å went up slightly and the response to 4700–5280 Å dropped somewhat. However, the peak response continued in 4700–5280 Å or in that region.

These two types of responses, weak to 3650–3663 Å (ultra-violet) and strong to 4700–5280 Å when the introductory intensity was 100 (1 foot from filters); and strong to 3650–3663 Å and weak to 4700–5280 Å when the introductory intensity was 3 (6 feet from filters) indicated that the ultra-violet at an intensity of 100 was too intense when the insects were exposed suddenly to it, and also that the behavior pattern or the sensitivity of the insects to the spectrum could be varied by varying the intensities to which the insects were first exposed. In other words, it was suspected that the relative stimulating efficiency of various wave-lengths, of equal intensities, in that portion of the spectrum between 3650 Å and 7400 Å could be changed, within certain limits, by changing the distances between the source of the light and the point at which the insects were first exposed to it. This changes the introductory intensities while the physical intensities of the sources remain constant. In all cases the insects, at the completion of the tests, were subjected to equal light intensities regardless of the initial or introductory intensities.

Although the insects under consideration behaved as if they had wave-length discrimination or a perception of color, they also changed their behavior when the introductory intensities, to which they were exposed, were changed. It should be kept in mind that the changed intensities took place equally for all the wave-lengths to which the insects were exposed and up to a certain point the insects were free to make their choice among wave-lengths of equal physical intensities.

If different parts of the spectrum are preferred on account of the apparent luminosity of these parts then a wave-length of 3650 Å and a region in the neighborhood of from 4700–5280 Å would appear to be the most luminous to most of the insects at the intensities used. Of course this is only an inference drawn from their behavior. By the same reasoning the relative indifference of our species to 3650–3663 Å (ultra-violet) at an intensity of 100 (1 foot from filters) may have been due to the fact that the introductory intensity at this wave-length was too great for them.

Because of the importance of intensity in influencing their behavior it should be noted here that of the total number of individuals exposed to an intensity of 100 (1 foot from filters) about 25 per cent remained in the centre of the apparatus and did not go to any filter chambers. When the introductory intensity was reduced to 3 (6 feet from filters) the percentage not going to any filter chambers increased to around 54 per cent. The factor of increased space permitting more freedom of movement may have some bearing on these percentages.

TABLE 3

Name	Date tested	Relative humidity during test	Temperature °C. during test	
			At start	At end
		Per cent		
Tenodera sinensis Sauss				
One-day-old nymphs	Feb. 25, 1941	30	24	25.0
One-day-old nymphs	Feb. 26, 1941	26	24	25.5
One-day-old nymphs	Feb. 27, 1941	30	21	24.0
One-day-old nymphs	Mar. 1, 1941	32	23	24.0
Leptinotarsa decemlineata Say	May 28, 1941	52	27	27.0
Megilla fuscilabris Muls.	Feb. 28, 1941	30	23	25.0
Myllocerus castaneus Roelofs	April 4, 1941	34	24	25.0
Macrocentrus ancylivorus	Mar. 7, 1941	30	23	24.0

This factor and the importance of the introductory intensity in determining the behavior to wave-length made it necessary to build another piece of equipment that was flexible enough to permit changes in the introductory intensities.

(3) BEHAVIOR OF THE POTATO BEETLE AND THE JAPANESE BEETLE TO WAVE-LENGTHS OF DIFFERENT INTRODUCTORY INTENSITIES

This work was conducted in two wooden, light-tight runways emanating at right angles to each other from an introduction chamber about 8.5 inches square. These runways were made in 1 foot sections that could be fastened together. Distal sections were equipped with sub-chambers, for the filters, and in which the insects could be trapped. By this means, it was possible to test the insects at distances of from 1 to 6 feet away from the light chamber, and consequently at different intensities (Fig. 6).

Because 3650–3663 Å and 4700–5280 Å were the wave-lengths to which the various species responded in the largest numbers, it was decided to operate these two in competition with each other at various intensities, *i.e.,* by introducing the insects at various distances from the sources of the wave-lengths. The results of these tests are shown in Tables 5 and 6. For example, using potato beetles, when the intensity of each of the competing wave-lengths was 100, 40 per cent of the reacting beetles went to ultra-violet and 60 per cent went to blue-blue-green. When the intensity of both was reduced to 25, 54 per cent went to ultra-violet and 46 per cent to blue-blue-green. When the intensities were further reduced the same type of progressive results continued. When the intensity reached 3, 80 per cent of the reacting beetles went to ultra-violet and 20 per cent to blue-blue-green.

The behavior of the Japanese beetle as shown in Table 6 followed the same trend when tested under similar conditions but the differences between the responses to the two wave-lengths at varying intensities were not so great as those for the potato beetle. Apparently with only two wave-length bands to choose from the Japanese beetle did not at different introductory intensities differentiate between them as sharply as did the potato beetle.

In our tests with the Japanese beetle, and with other photo-positive insects as well, where the physical intensities of the wave-lengths were equalized, either at 100, or 3, or some other figure, in nearly all cases that portion of the spectrum from about 5300 Å to 7400 Å had comparatively little attractive value. However, this was true only when that part of the spectrum was competing with the blue end at equal intensities.

TABLE 4

Name	Date tested	Relative humidity during test	Temperature °C. during test	
			At start	At end
		Per cent		
Celetes basalis Lec.	July 11, 1941	60	28.0	28.1
Coccinella novemnotata Hbst.	June 18, 1941	64	27.0	27.2
Disonycha quinquevittata Say	Aug. 4, 1941	40	29.0	29.5
Blepharida rhois Forst.	July 17, 1941	80	27.5	27.6
Blepharida rhois Forst.	July 18, 1941	73	27.0	27.0
Chrysochus auratus (Fab.)	June 26, 1941	50	27.0	27.0
Lina lapponica Linn.	June 7, 1941	55	25.0	25.1
Lina lapponica Linn.	June 23, 1941	62	29.0	29.0
Galerucella xanthomelaena Schr.	May 2, 1941	28	24.5	25.0
Plagiodera versicolora Laich.	May 12, 1941	41	24.5	25.0
Crioceris asparagi Linn.	May 9, 1941	45	26.0	26.0
Crioceris asparagi Linn.	May 15, 1941	45	26.0	26.0
Tetraopes tetraophthalmus Foer.	June 19, 1941	64	27.0	27.8
Tetraopes tetraophthalmus Foer.	June 18, 1941	60	27.0	27.0
Hylurgopinus rufipes (Eich.)	July 30, 1941	90	28.0	28.0
Scolytus multistriatus Marsh.	June 6, 1941	45	24.2	25.0
Scolytus multistriatus Marsh.	July 30, 1941	90	27.0	27.5
Serica iricolor Say	May 19, 1941	40	25.2	26.0
Macrodactylus subspinosus Fab.	June 9, 1941	38	26.0	26.0
Macrodactylus subspinosus Fab.	May 29, 1941	47	31.0	32.0
Autoserica castanea Arrow	July 11, 1941	62	29.5	29.5
Leptinotarsa decemlineata Say	May 21, 1941	52	26.2	26.4
Leptinotarsa decemlineata Say	May 28, 1941	62	28.0	29.0
Leptinotarsa decemlineata Say	June 10, 1941	25	26.0	27.0
Leptinotarsa decemlineata Say	June 3, 1941	52	26.1	26.5
Galerucella notata (Fab.)	Sept. 12, 1941	35	27.0	27.0
Popillia japonica Newm.	June 12, 1941	86	25.5	25.5
Popillia japonica Newm.	June 16, 1941	55	26.0	26.2
Popillia japonica Newm.	June 17, 1941	55	26.0	26.5
Popillia japonica Newm.	July 31, 1941	70	29.0	29.5
Popillia japonica Newm.	July 31, 1941	70	29.0	29.5
Popillia japonica Newm.	July 31, 1941	70	29.0	29.5
Popillia japonica Newm.	Aug. 14, 1941	40	29.0	29.0
Popillia japonica Newm.	Aug. 15, 1941	64	26.0	26.0
Macrocentrus ancylivorus	April 23, 1941	38	25.0	25.5
Apis mellifica L.	April 30, 1941	29	24.9	25.0
Apis mellifica L.	June 23, 1941	62	29.0	29.0
Leptocoris trivittatus Say	Oct. 2, 1941	42	26.0	26.0

Table 7 sets forth the results obtained with the Japanese beetle when ultra-violet and blue-blue-green at low introductory intensities competed with other colors in the red end of the spectrum at comparatively high introductory intensities. These tests were made in the apparatus last described, the runways being at right angles to each other. For example infra-red (6620–7400 Å), which attracted practically nothing in former tests where the intensities were equalized, attracted 10 per cent of the beetles when used at an intensity of 100 in competition with ultra-violet (3650–3663 Å) at an intensity of 3, which attracted 90 per cent.

TABLE 5

BEHAVIOR OF THE POTATOE BEETLE, *Leptinotarsa decemlineata*, TO ULTRA-VIOLET, AND BLUE-BLUE-GREEN LIGHTS IN COMPETITION AT VARYING INTRODUCTORY INTENSITIES

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Per cent reacting to 3650–3663 Å (Ultra-violet)	Per cent reacting to 4700–5280 Å (Blue-blue-green)	Relative physical intensity of each wave-length band
				Minutes			
3	297	26	74	15	40	60	100
3	386	19	81	15	54	46	25
4	428	39	61	45	62	38	11
1	159	11	89	20	60	40	6
1	159	3	97	20	71	29	4
1	144	13	87	30	80	20	3
1	115	30	70	30	50	50	100
1	103	18	82	15	70	30	11
1	121	33	67	15	79	21	3
1	95	26	74	15	57	43	100
1	117	26	74	15	65	35	11
1	138	30	70	30	78	22	3

Orange-red (6120–6860 Å), another unattractive wave-length at equal intensities, when used at an intensity of 100 in competition with ultra-violet (3650–3663 Å) at 3 attracted 49 per cent of the insects. This type of behavior held true for the colors yellow-orange (5900–6420 Å), yellow-yellow-green (5550–6070 Å) and yellow-green (5300–5760 Å) when used in competition with ultra-violet (3650–3663 Å) under the same conditions.

The same behavior took place when blue-blue-green (4700–5280 Å) instead of ultra-violet was used in competition with the colors previously used. The intensity of the blue-blue-green was 3 and that of the other colors was 100. The results of these tests are also shown on Table 7.

Infra-red was not very attractive even at the greatly increased intensity and most of the beetles preferred to travel 6 feet to either ultra-violet or blue-blue-green, when the introduction intensity was 3, rather than 1 foot to the infra-red when the introduction intensity was 100. Another seemingly unattractive wave-length band, blue (4420–5000 Å), indicated by the constant dip in the behavior curves was also found to be attractive when the insects were introduced to it at a greatly increased intensity.

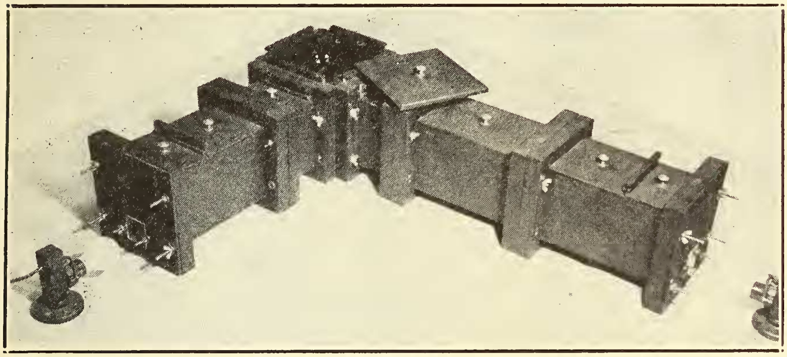

FIG. 5. Two-way apparatus, showing introduction chamber and several sections.

This behavior indicates that, within certain limits, relatively unattractive parts of the spectrum can be made attractive by increasing their intensities.

In order to find out what would happen if the insects were given a smaller choice of wave-length bands and if this choice were successively narrowed by eliminating one band after each trial, one half of the sector type of apparatus was used and the insects were exposed three feet away from the filters or at an introductory intensity of 11.

The results of these tests are outlined in Tables 8 to 11, the potato beetle and the Japanese beetle being utilized because of their availability. As will be noted in Table 8, potato beetles were exposed to five bands extending from 3650 to 5660 Å for 30 minutes, and the reacting beetles went, in almost equal numbers, to every band except blue and blue-green. At the end of the next test which involved four bands, the blue-green having been dropped, the beetles again went in almost equal numbers to everything except blue. In the third test, with three bands to choose from the response was equal to ultra-violet and violet-blue, and low to blue. In the fourth test, involving two favorable colors, 62 per cent went to violet-blue. In the fifth test, the insects had no choice. It should be noted that throughout the tests the numbers reacting held up fairly uniformly.

TABLE 6

Behavior of the Japanese Beetle, *Popillia japonica*, to Ultra-violet and Blue-blue-green Lights in Competition at Varying Introduction Intensities

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Per cent reacting to 3650–3663 Å (Ultra-violet)	Per cent reacting to 4700–5280 Å (Blue-blue-green)	Relative physical intensity of each wave-length band
				Minutes			
1	117	38	62	15	44	56	100
1	94	40	60	15	41	59	25
1	98	35	65	20	53	47	11
1	107	20	80	25	58	42	6
1	101	39	61	25	56	44	4
1	108	21	79	30	61	39	3
1	122	14	86	15	38	62	100
1	119	32	68	15	25	75	25
1	98	9	91	20	45	55	11
1	114	4	96	20	34	66	6
1	115	5	95	20	45	55	4
1	108	0	100	20	52	48	3
1	115	14	86	15	37	63	100
1	116	11	89	15	25	75	25
1	125	39	61	15	50	50	11
1	152	20	80	40	40	60	6
1	136	23	77	50	47	53	4
1	160	34	66	30	31	69	100
1	221	22	78	30	44	56	11
1	133	36	64	35	54	46	3

The results of a similar test, with the Japanese beetle, in which one band was dropped after each test, are shown in Table 9. In four of the five tests blue-green was the least attractive color, and blue-blue-green nearly always the most attractive one. In the fifth test, where there was no choice, all went to blue-green, but only half the number of beetles reacted in comparison with previous tests.

In the next two series of tests, the insects were exposed to five bands extending from 5300 to 7400 Å and one band was dropped after each test, as formerly. In previous tests where the exposure was to 10 bands extending from 3650 to 7400 Å, that portion of the spectrum from about 5300 to 7400 Å was always relatively unattractive. Therefore, in Tables 10 and 11, the behavior is shown when the insects were given a choice in what previously was a series of unfavorable wave-length bands.

Forty per cent of the potato beetles in the first test went to yellow-green and the smallest percentage to infra-red. In the second test, with yellow-green omitted, the preference was for yellow-yellow-green. In fact, as the favorite color in each test was eliminated, the color nearest the omitted one, and the most distant from infra-red, became the favored one. This kept up until all went to infra-red, but a fewer number reacted. In fact, only 28 per cent reacted to infra-red while double this percentage reacted to the bands in the other tests.

In Table 11 the behavior of the Japanese beetle is shown to the same sort of tests. And in general the results are similar to those obtained with the potato beetle. However, with the third test to 3 wave-length bands, the number reacting declined and this decline was considerable when the beetles had no choice except infra-red. In this case only 2 per cent reacted, which is negligible.

From the behavior as indicated in Tables 8 to 11, it would appear that a certain proportion of potato beetles and Japanese beetles, when confined in a roomy apparatus, and exposed to various wave-length bands, will respond positively to almost every part of the spectrum between 3650 and 5660 Å at an intensity of 11. If the band in this portion of the spectrum is narrowed so that they are limited in their choice, in general they will respond just as well to the narrower portion.

TABLE 7

BEHAVIOR OF THE JAPANESE BEETLE, *Popillia japonica*, TO ULTRA-VIOLET AND BLUE-BLUE-GREEN LIGHT OF LOW INTENSITY IN COMPETITION WITH VARIOUS OTHER COLORS AT COMPARATIVELY HIGH INTENSITIES

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Wave-length bands	Relative physical intensity	Per cent reacting	Wave-length bands	Relative physical intensity	Per cent reacting
				Minutes	*Ångstrom*			*Ångstrom*		
3	501	26	74	15	3650–3663	3	90	6620–7400	100	10
3	676	17	83	15	3650–3663	3	51	6120–6860	100	49
3	477	47	53	15	3650–3663	3	49	5900–6420	100	51
3	517	17	83	15	3650–3663	3	34	5500–6070	100	66
3	740	29	71	15	3650–3663	3	37	5300–5760	100	63
1	237	21	79	15	4700–5280	3	81	6620–7400	100	19
1	227	3	97	15	4700–5280	3	41	6120–6860	100	59
1	222	12	88	15	4700–5280	3	33	5900–6420	100	67
1	235	8	92	15	4700–5280	3	21	5500–6070	100	79
1	218	15	85	15	4700–5280	3	19	5300–5760	100	81
3	512	22	78	15	3650–3663	3	38	4420–5000	100	62
3	649	52	48	15	3650–3663	11	36	5900–6420	100	64
3	478	11	89	15	3650–3663	11	26	5500–6070	100	74

It is also indicated that when the same insects are exposed to various bands in that part of the spectrum between 5300 and 7400 Å at an introductory intensity of 11 a pronounced response will take place to every wave-length band except that of infra-red. If the band in this portion of the spectrum is narrowed, the greatest response will take place, as a rule, to the bands furthest removed from infra-red. Although the response to infra-red appears significant from a percentage standpoint, it is really not significant from the standpoint of actual numbers.

TABLE 8

BEHAVIOR OF THE POTATO BEETLE TO FIVE WAVE-LENGTH BANDS IN THE BLUE END OF THE SPECTRUM, WITH ONE BAND ELIMINATED AFTER EACH TEST

(Physical intensities of wave-lengths equalized at 11)

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Wave-length band	Per cent reacting	Color of light transmitted
				Minutes	*Ångstrom*		
1	157	50	50	30	3650–3663	28	Ultra-violet
					4120–4760	25	Violet-blue
					4420–5000	9	Blue
					4700–5280	23	Blue-blue-green
					4940–5660	15	Blue-green
1	180	48	52	30	3650–3663	28	Ultra-violet
					4120–4760	28	Violet-blue
					4420–5000	13	Blue
					4700–5280	31	Blue-blue-green
1	179	49	51	30	3650–3663	40	Ultra-violet
					4120–4760	40	Violet-blue
					4420–5000	20	Blue
1	149	51	49	30	3650–3663	38	Ultra-violet
					4120–4760	62	Violet-blue
1	141	58	42	30	3650–3663	100	Ultra-violet

It should be kept in mind that the behavior as reported in Tables 8 to 11 took place at an introductory intensity of 11, and that in all likelihood the ratios would be significantly changed if there was a corresponding change in the introductory intensity.

NOTES

All tests were made during daylight from 9:00 A.M. to 4:00 P.M., except for *Autoserica castanea.* This species exhibited little or no interest in light even after being kept in a dark place 10 or 15 minutes before testing. The tests as recorded were made at 9:00 P.M., D.S.T. As this is a nocturnal species we believe that an even greater percentage would have reacted if the tests had been made later in the evening.

The individuals of many species were in copulation during the tests, this being particularly true of *Chrysochus auratus, Macrodactylus subspinosus, Popillia japonica* and *Leptinotarsa decemlineata.* This and the gregariousness of some species may have added something to the number of individuals going to a certain color but not enough to warrant serious consideration. As a rule the three tests that were made for many species were fairly uniform.

TABLE 9

BEHAVIOR OF THE JAPANESE BEETLE TO FIVE WAVE-LENGTH BANDS, IN THE BLUE END OF THE SPECTRUM, WITH ONE BAND ELIMINATED AFTER EACH TEST

(Physical intensities of wave-lengths equalized at 11)

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Wave-length band	Per cent reacting	Color of light transmitted
				Minutes	*Angstrom*		
1	370	30	70	15	3650–3663	11	Ultra-violet
					4120–4760	21	Violet-blue
					4420–5000	31	Blue
					4700–5280	30	Blue-blue-green
					4940–5660	7	Blue-green
1	357	38	62	15	4120–4760	24	Violet-blue
					4420–5000	23	Blue
					4700–5280	38	Blue-blue-green
					4940–5660	15	Blue-green
1	284	53	47	15	4420–5000	26	Blue
					4700–5280	52	Blue-blue-green
					4940–5660	22	Blue-green
1	294	32	68	15	4700–5280	81	Blue-blue-green
					4940–5660	19	Blue-green
1	245	65	35	15	4940–5660	100	Blue-green

In the case of *Apis mellifica,* field bees on their way out of the hive were used. It was found that if well fed the bees had a tendency to stay in the introduction chamber.

Tiphia vernalis (Hymen.). Males of this species were used twice, once on May 7 and again on June 14. After an exposure of 20 minutes to 10 wave-length bands practically all the insects in both instances remained in the introduction chamber or the center of the apparatus. Apparently an introductory intensity of 3 was not a strong enough one to stimulate them.

Cryptorhynchus lapathi (Col.). This weevil was tested twice, about 130 adults being used in each test, but the response to the light was very poor. Ninety per cent of the beetles went either to the dark chamber or remained in the introduction compartment. These tests were made on July 8 at an introductory intensity of 3.

Cicindela repanda (Col.). Fifty adults of this tiger beetle were exposed twice on August 22, once at an introductory intensity of 3 and again at an introductory intensity of 11. In both cases practically all the beetles remained where they were first introduced. In comparison with bright sunlight to which these insects are frequently accustomed, both our introductory intensities must have seemed like darkness to them. They moved only when a moving object such as a hand approached them in order to pick them up. It was unexpected to find these active insects, after an exposure of 15 minutes, in exactly the same place where they had been introduced. Some had not moved at all and others had not moved more than an inch or two. They seemed to be hypnotized at the low intensities of the various wave-lengths.

Aedes ægypti (Dip.). Two hundred and fifteen adults of the yellow fever mosquito were tested on September 24 at an introductory intensity of 3 and not a single one went to any of the 10 wave-length bands. Seventy-five per cent remained in the introduction chamber and 25 per cent went to the black chamber.

Pyrausta nubilalis (Lep.). Adults of this species were tested in lots of 100 and more during the daytime on May 20 and May 26, at an intensity of 3. After an exposure of 35 minutes in one case and 60 minutes in another only a few insects were found in the ultra-violet and blue-blue-green compartments. Most of them were in the introduction compartment. Different results might have been obtained if the testing had been done at night.

SUMMARY AND DISCUSSION

Twenty-nine species of insects, mostly Coleopterous and diurnal, were exposed to from eight to ten light bands of equal physical intensities in that part of the spectrum from 3650 to 7400 Ångstrom units. The physical intensities of the wave-lengths were equalized by the methods set forth in the JOURNAL OF THE NEW YORK ENTOMOLOGICAL SOCIETY, Vol. XLIX, p. 1–20, 1941. The introductory intensities of the wave-lengths were changed in some cases by exposing the insects at different distances from the source of light. When the insects under consideration were exposed to the various colors at an introductory intensity of 100 the peak response, for most of them, took place at 4700–5280 Å (blue-blue-green). When the introductory exposure was at an intensity of 3, the peak response took place at 3650–3663 Å. In nearly all cases the responses to 5550–7400 Å were insignificant, when the insects were exposed to the blue end of the spectrum as well.

TABLE 10

BEHAVIOR OF THE POTATO BEETLE TO FIVE WAVE-LENGTH BANDS IN THE SPECTRUM FROM GREEN TO INFRA-RED WITH ONE BAND ELIMINATED AFTER EACH TEST

(Physical intensities of wave-lengths equalized at 11)

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Wave-length band	Per cent reacting	Color of light transmitted
				Minutes	*Ångstrom*		
1	144	54	46	30	5300–5760	40	Yellow-green
					5500–6070	21	Yellow-yellow-green
					5900–6420	26	Yellow-orange
					6120–6860	10	Orange-red
					6620–7400	3	Infra-red
1	150	52	48	30	5500–6070	46	Yellow-yellow-green
					5900–6420	18	Yellow-orange
					6120–6860	24	Orange-red
					6620–7400	12	Infra-red
1	135	58	42	30	5900–6420	66	Yellow-orange
					6120–6860	23	Orange-red
					6620–7400	11	Infra-red
1	121	55	45	30	6120–6860	76	Orange-red
					6620–7400	24	Infra-red
1	110	72	28	30	6620–7400	100	Infra-red

The behavior of the potato beetle and the Japanese beetle to ultra-violet and blue-blue-green in competition with each other indicated that the sensitivity of the insects to these wave-lengths or colors, varied in accordance with the introductory intensities.

Tests made with the Japanese beetle alone, using ultra-violet and blue-blue-green in competition with 5 wave-lengths or colors mostly in the so-called red end of the spectrum indicated that parts of the red end at intensities of 100 are more attractive than ultra-violet and blue-blue-green at intensities of 3.

TABLE 11

BEHAVIOR OF THE JAPANESE BEETLE TO FIVE WAVE-LENGTH BANDS IN THE SPECTRUM FROM GREEN TO INFRA-RED WITH ONE BAND ELIMINATED AFTER EACH TEST

(Physical intensities of wave-lengths equalized at 11)

No. tests	No. insects involved	Per cent not reacting	Per cent reacting	Exposure	Wave-length band	Per cent reacting	Color of light transmitted
				Minutes	*Ångstrom*		
1	320	33	67	15	5300–5760	21	Yellow-green
					5550–6070	33	Yellow-yellow-green
					5900–6420	30	Yellow-orange
					6120–6860	16	Orange-red
					6620–7400	0	Infra-red
1	288	35	65	15	5550–6070	36	Yellow-yellow-green
					5900–6420	32	Yellow-orange
					6120–6860	29	Orange-red
					6620–7400	3	Infra-red
1	230	60	40	15	5900–6420	57	Yellow-orange
					6120–6860	36	Orange-red
					6620–7400	7	Infra-red
1	187	68	32	15	6120–6860	83	Orange-red
					6620–7400	17	Infra-red
1	176	98	2	15	6620–7400	100	Infra-red

Additional tests with the potato beetle and Japanese beetle, in which they were exposed at first to five wave-length bands which were progressively reduced to one, indicated that at an intensity of 11, in the absence of a favored color, these insects will respond to all test colors except infra-red.

In view of these results with the species under consideration it is apparent that they behaved as if they had wave-length or color discrimination. With the physical intensities of the colors equalized, and at a certain introductory intensity at exposure to the colors, an almost uniform type of behavior pattern was apparent for many species, with the most stimulating part of the spectrum being confined to certain of the shorter wave-lengths. When the introductory intensity was changed the behavior pattern changed also, this change taking place in the response to the blue end of the spectrum and involving specifically the sensitivity of the insects to 3650–3663 Å, and 4700–5280 Å.

These and the other types of behavior to colors which occurred when the physical intensities were changed suggest that the stimulating values of the wave-lengths may be due in large part to their apparent luminosity, or to some other effect of wave-length and intensity upon the visual apparatus. Although apparent luminosity can only be inferred from the actions of the insects, it seems to offer a satisfactory explanation for the varied behavior. It is our belief that of the two factors, wave-length and intensity, the latter is by far the most important. Of course the relative importance of each can only be determined by experimental work designed to bring out the thresholds of reflex action for various species exposed to different wave-lengths at different intensities.

It should be kept in mind that the work reported upon in this and the two previous papers is intended to be exploratory rather than exhaustive in any particular aspect. After studying the general behavior of many species to various wave-lengths, information is obtained that is invaluable in planning further work in a narrower and more specialized phase. The results therefore, so far, should be interpreted as indicating trends of behavior for large numbers of insects rather than as types of behavior that are fixed and inflexible. Not all individuals in a group of one species or another are equally photosensitive at the same time. Our specimens, as they were collected in the field, included individuals of different ages and certainly many of them were under outer and internal stimuli that modified or inhibited their response to light. Care was taken to use fresh specimens in every test. When this was not possible, the tests were discontinued when it became apparent that too much handling or too many successive exposures were reducing their sensitivity.

Although artificial light is a poor substitute for sunlight, the use of reflected sunlight of uniform and constant quality seems unattainable. And although the tests were artificial in that insects are not called upon in nature to make choices between such wave-lengths as we placed before them, no better method presented itself. Out of doors, insects are subjected to a variable distribution of energy in the visible spectrum of daylight. Haze, dust, clouds, smoke absorb certain wave-lengths. Taylor and Kerr, who have recently measured the relative spectral energy distribution of daylight, show in a recent paper some of the nor-

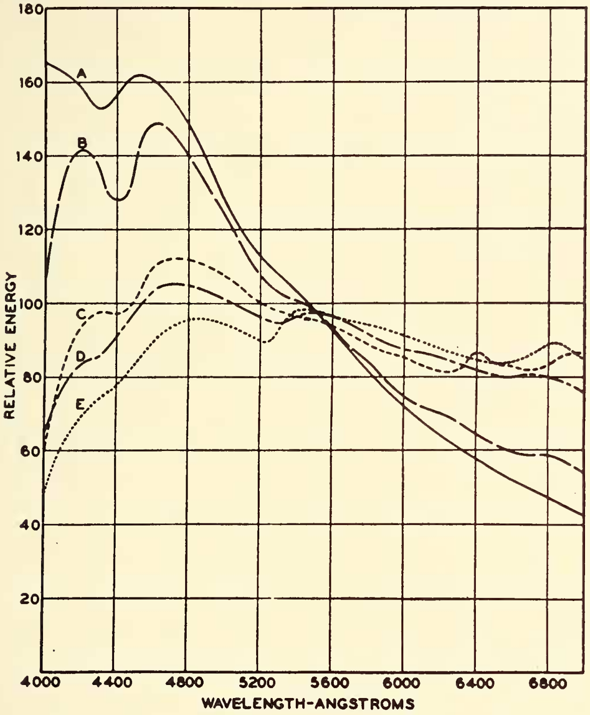

FIG. 6. Average energy distribution curves for following types of daylight: (A) Zenith sky, color temperature 13,700° K; (B) North sky on 45° plane, color temperature 10,000° K; (C) Totally overcast sky, color temperature 6500° K; (D) Sun plus sky on horizontal plant, color temperature 6000° K; (E) Direct sunlight, color temperature 5335°K. (After A. H. Taylor and G. P. Kerr.)

mal variations in the distribution of energy from 4000 to 7000 Å. While these variations represent only a small part of the entire range found in nature they do not seem to be very great for sunlight and are not nearly so great as the changes in introductory physical intensities to which we subjected our experimental insects. For example a reduction in relative physical intensity from 100 to 3 is approximately a change of 3300 per cent. Such relatively small comparative variations as occur in nature during the mid-day sunlight hours, in which many insects are active, probably influence insect behavior little or not at all.

When we used 100 watt lamps instead of 40 watt lamps, thereby increasing the physical intensity approximately 250 per cent, the responses of the species showed no appreciable change. Figure 7 shows average energy distribution curves, for certain types of daylight, as plotted by Taylor and Kerr.

ACKNOWLEDGMENTS

For supplying the specimens used in the tests we are greatly indebted to Mr. Robert J. Sim, Mr. Paul L. Holcombe, Mr. Lewis P. Hoagland, Mr. C. W. Collins, Mr. Max P. Zappe, Dr. Philip Garman, Dr. J. L. King, Dr. R. W. Glaser, and Mr. John H. Harman.

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PLATE I

Figure 1. *Crioceris asparagi*
Figure 2. *Lina lapponica*
Figure 3. *Lina lapponica*
Figure 4. *Tetraopes tetraophthalmus*
Figure 5. *Serica iricolor*
Figure 6. *Chrysochus auratus*
Figure 7. *Plagiodera versicolora*
Figure 8. *Autoserica castanea*
Figure 9. *Hylurgopinus rufipes*
Figure 10. *Scolytus multistriatus*
Figure 11. *Macrodactylus subspinosus*
Figure 12. *Macrodactylus subspinosus*
Figure 13. *Coccinella 9-notata*
Figure 14. *Disonycha quinquevittata*
Figure 15. *Blepharida rhois*
Figure 16. *Blepharida rhois*
Figure 17. *Apis mellifica*
Figure 18. *Apis mellifica*
Figure 19. *Galerucelia xanthomelaena*
Figure 20. *Macrocentrus ancylivorus*
Figure 21. *Macrocentrus ancylivorus*
Figure 22. *Celetes basalis*

Note: Figures in parentheses below names on plate indicate the relative intensities of wave-lengths.

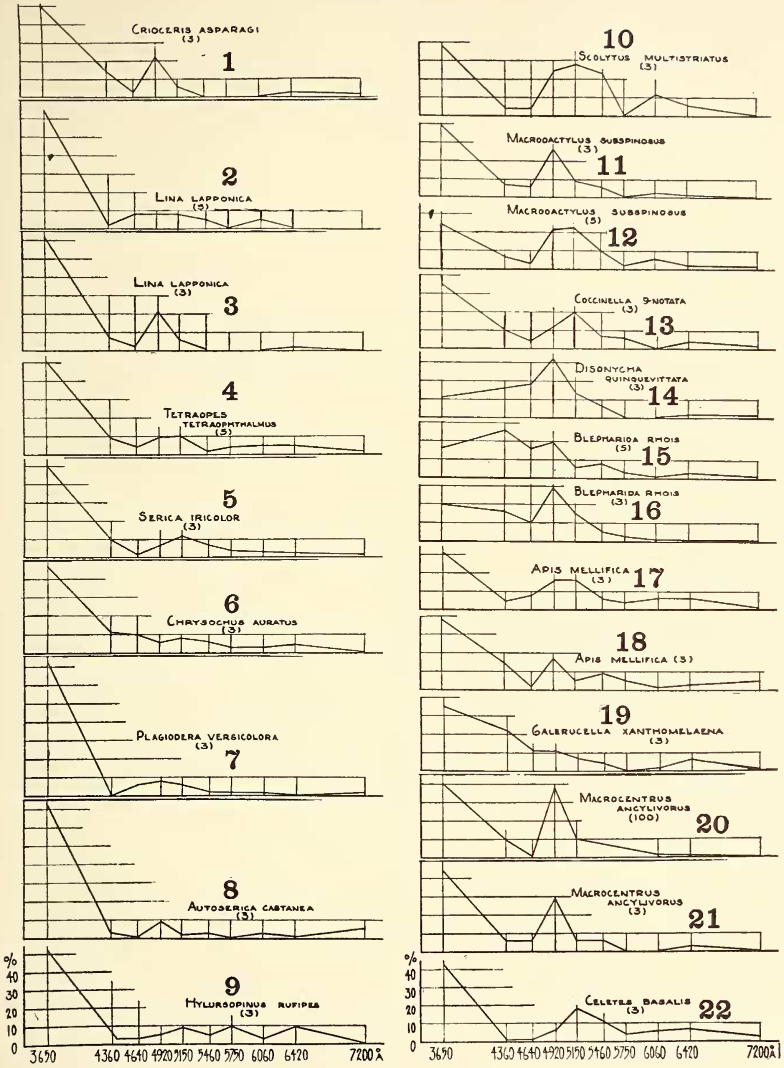
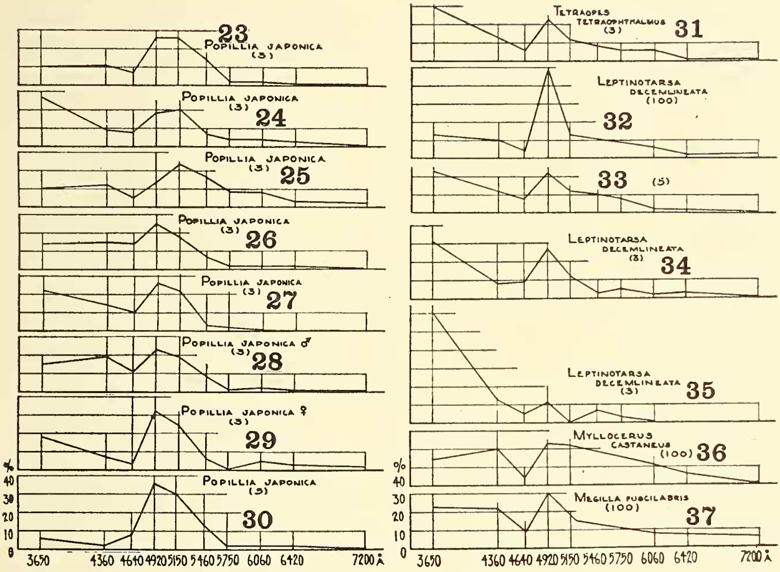

1
CRIOCERIS ASPARAGI (3)
2
LINA LAPPONICA (5)
3
LINA LAPPONICA (3)
4
TETRAOPES TETRAOPHTHALMUS (5)
5
SERICA IRICOLOR (3)
6
CHRYSOCHUS AURATUS (3)
7
PLAGIODERA VERSICOLORA (3)
8
AUTOSERICA CASTANEA (3)
9
HYLURGOPINUS RUFIPES (3)
10
SCOLYTUS MULTISTRIATUS (3)
11
MACRODACTYLUS SUBSPINOSUS (3)
12
MACRODACTYLUS SUBSPINOSUS (5)
13
COCCINELLA 9-NOTATA (3)
14
DISONYCHA QUINQUEVITTATA (3)
15
BLEPHARIDA RHOIS (5)
16
BLEPHARIDA RHOIS (3)
17
APIS MELLIFICA (3)
18
APIS MELLIFICA (3)
19
GALERUCELLA XANTHOMELAENA (3)
20
MACROCENTRUS ANCYLIVORUS (100)
21
MACROCENTRUS ANCYLIVORUS (3)
22
CELETES BASALIS (3)
%
40
30
20
10
0
3650
4360
4640
4920
5150
5460
5750
6060
6420
7200 Å

PLATE II

Figure 23. *Popillia japonica*
Figure 24. *Popillia japonica*
Figure 25. *Popillia japonica.* Filter positions in disarray.
Figure 26. *Popillia japonica*
Figure 27. *Popillia japonica*
Figure 28. *Popillia japonica*
Figure 29. *Popillia japonica*
Figure 30. *Popillia japonica*
Figure 31. *Tetraopes tetraophthalmus*
Figure 32. *Leptinotarsa decemlineata*
Figure 33. *Leptinotarsa decemlineata*
Figure 34. *Leptinotarsa decemlineata*
Figure 35. *Leptinotarsa decemlineata*
Figure 36. *Myllocerus castaneus*
Figure 37. *Megilla fuscilabris*

NOTE: Figues in parentheses below names on plate indicate the relative intensities of wave-lengths.


23
POPILLIA JAPONICA
(3)
POPILLIA JAPONICA
(3)
24
POPILLIA JAPONICA
(3)
25
POPILLIA JAPONICA
(3)
26
POPILLIA JAPONICA
(3)
27
POPILLIA JAPONICA ♂
(3)
28
POPILLIA JAPONICA ♀
(3)
29
POPILLIA JAPONICA
(3)
30
%
40
30
20
10
0
3650
4360
4640
4920
5150
5460
5750
6060
6420
7200 Å
TETRAOPES
TETRAOPHTHALMUS
(3)
31
LEPTINOTARSA
DECEMLINEATA
(100)
32
33
(5)
LEPTINOTARSA
DECEMLINEATA
(3)
34
LEPTINOTARSA
DECEMLINEATA
(3)
35
MYLLOCERUS
CASTANEUS
(100)
36
%
40
30
20
10
0
MEGILLA FUSCILABRIS
(100)
37
3650
4360
4640
4920
5150
5460
5750
6060
6420
7200 Å